Arch. Met. Geoph. Biokl., Ser. B, 21, 110—116 (1973)
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551.586

Physiological Effects of Electromagnetic Fields in the ELF Region

II. A Review[1]

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Received August 28, 1972

Summary

Recent investigations on physiological effects of pre- and neo-natal exposure to an ELF rotating magnetic field on rats show that considerable changes in the behavior and in thyroid and testicle weights are to be found. The possible reaction mechanism is discussed in detail, but there is no final concept.

The present experiments, especially those concerned with the conditioned responses of rats that had been exposed during various phases of pre- and neo-natal development, characterize the general findings to date and problems to be solved. A possible influence of ELF fields on the growth of the nervous system suggests interesting consequences in the development of the organism far from the surface of the earth.

Zusammenfassung

Physiologische Wirkung elektromagnetischer Wellen bei tiefen Frequenzen. Historischer Überblick und gegenwärtiger Stand der Forschung. Teil II[1]

Die neuesten Forschungen über den prä- und perinatalen Einfluß von ELF-Wellen auf Ratten bzw. Rattenembrios zeigen, daß eine erhebliche Änderung des Verhaltens und eine starke Veränderung des Drüsengewichtes, insbesondere des der Schilddrüse, die Folge sind. Denkbare Wirkungsmechanismen der ELF-Wellen werden ausführlich diskutiert, ohne daß endgültige Vorstellungen gewonnen werden können.

Die noch laufenden Experimente, insbesondere Untersuchungen bedingter Reflexe von Ratten, die während verschiedener Phasen der Embryonalentwicklung ausgesetzt waren, sollen noch offenstehende Fragen klären. Ein möglicher Einfluß der ELF-Wellen auf das Nervenwachstum würde weitreichende Konsequenzen auf die Entwicklung von Organismen fern von der Erdoberfläche haben.

[1] By M. A. Persinger and K.-P. Ossenkopp.

One interesting area of ELF research that has only recently been investigated is concerned with the physiological and behavioral consequences of prenatal exposure to these fields. There is no doubt that the developing organism is very suceptible to such environmental factors as ionizing radiation, hormone injections, or nutritional deficits, which have been demonstrated to have long lasting effects on the biochemistry, cyto-architecture, physiology and behavior. In the CNS (central nervous system) alone, during the development of the fetus there are many processes which might be influenced by ELF or VLF exposure. Cells migrate from their proliferative matrices, axons grow by processes (which are still unclear) to particular cell nuclei, and chemical systems (e. g., catecholamines, tryptophans) associated with later adult behavioral changes are being synthesized during this period. From the equations developed in previous papers [13], for example, ELF and VLF wave bands could have the capacity to affect axoplasmic transport by modifying such processes as axonal peristalsis, axial gradients of oxygen permeability, or microtuble cytoplasmic streaming. The previous reaction is triggered by calcium ions [12], which according to Ludwig's equations can be altered by ELF absorption. Logically, ferric and oxygen systems are also candidates for ELF prenatal effects.

Persinger, Ossenkopp and their associates have demonstrated that prenatal exposure to a 0.5 Hz, 0.5—30 gauss (10^{-4} V/m) rotating magnetic field (RMF) can result in a variety of behavioral and physiological changes. Rats that had been exposed continuously during their prenatal development to this ELF field, but removed at birth, showed less ambulatory behavior but greater defecation in an open field test [14, 16]. In a free-operant avoidance situation, where the animal could postpone an electric shock by pressing a lever, the ELF-RMF-exposed rats showed significantly less bar pressing, but received similar numbers of shocks relative to control animals [18]. Suggesting that these results indicated that the ELF-exposed rats were attenuating their behavior or "freezing" in the presence of aversive stimuli, Persinger and Pear [19] tested ELF-exposed and control rats in a conditioned suppression task, a situation in which any "freezing" of ongoing behavior would be amplified. In this task the rats were trained to press a lever at a regular rate for food reinforcement. The delivery of the food was contingent upon a programmed variable interval schedule [2]. Once this was established, the house light in the operant test chamber was turned off for four minutes twice per test session. The four minute period of darkness

was called the CS (conditioned stimulus). When the animals had habituated to this change of stimuli and had resumed regular responding through the session, a mild 0.5 second shock was delivered at the end of the CS periods. The experimenters predicted that if the data were consistent, the ELF-RMF-exposed rats should show more disruption of their ongoing response rates than controls during the CS. In three experiments, it was found that during the first few pairings of CS with electric shock, the experimental animals did show significantly more suppression of response rate during the CS periods. Consequent pairings at this shock intensity resulted in similar suppression rates in the control groups. Persinger and Pear concluded that the data implied an increase in autonomic reactivity to novel or aversive stimuli, including the anticipation of aversive stimuli, by the ELF-RMF-exposed animals. Such behavior has been termed as increased "fearfulness", "emotionality" or "anxiety".

Since similar behavioral patterns have been shown to be associated with hypothyroid-like conditions [3, 4, 5]. Ossenkopp, Koltek, and Persinger [15] examined the thyroid tissue of RMF-exposed and control rats. They found a significant increase in relative thyroid weight in the experimental animals, relative to controls. In addition, the RMF-exposed rats also showed a significant increase in relative testicle weights. No significant changes were noted in blood sugar or circulating eosinophil count levels. Ossenkopp [14], suggesting that such changes might be residual effects of an earlier hypothyroid state associated with prenatal RMF exposure, recorded the eye opening, teeth eruption, and startle reflex development in rat pups from RMF and control litters. He found no consistent differences between groups with respect to the startle reflex development, but significant retardation of teeth eruption and eye opening in the RMF-exposed pups. The later two properties are characteristic of relative hypothyroid animals. If these effects are consistent, then definite changes in the CNS as well as other parts of the body might have occurred also. It has been shown that thyroidectomy at birth results in hypothyroid-induced disruption of granule cell migration and Purkinje cell dendritic arborization in the cerebellum [10] abberrant cytoarchitecture in some cerebral cortical layers, and alterations in cholinesterase [6] and other chemical systems [10].

One explanation for the hypothyroid-like characteristics of adult rats that have been exposed *prenatally* to the ELF-RMF may be found in the results of *adult* exposure to these fields. Persinger, Glavin and Ossenkopp [20] reported that adult exposure to the 0.5 Hz 0.5—3 gauss or 3—30 gauss field was associated with *de-*

creased thyroid weights and behaviors more characteristic of relative *hyper*thyroidism. If, in the pregnant female RMF exposure produced an increase in thyroid chemicals which altered the fetal environment, then at birth when the neonate is removed from the field and mother's chemical systems, a net hypothyroid level (relative to controls) may have developed. The specific physiological mechanism by which this occurs is unclear. In both prenatal and adult exposure situations, the thyroid is affected. However this does not obviate the participation of endocrine-feedback systems, especially the hypothalamic-hypophysis system. Although the follicular concentration of colloid in the thyroid may fit the conditions for VLF, if not ELF absorption, Ludwig [13] has calculated that this effect should be secondary. The major effect, according to his equations should occur within the more densely vascularized and neuronally packed pituitary or adjacent hypothalamic nuclei. In fact, the behavioral and physiological changes noted in adult rats exposed to the ELF field which were ascribed to possible thyroid change [20] have been shown to occur following stimulation or lesioning of the hypothalamic-pituitary complex [7]. Conceivably, exposure of the pregnant female to the EMF-RMF could result in pituitary and consequent thyroidal changes, which could be communicated to the fetus after prenatal day 19 [1, 11]. Direct effects on the fetal hypothalamic-pituitary system also seems possible, although the communication routes (median eminence) between the hypothalamus and pituitary do not mature in the rat until some days after birth (when the animals had been removed from the field).

One final point concerning prenatal exposure to ELF fields may be of importance. It has been reported from the area of radiobiology (ionizing radiation) that the time of prenatal exposure to the ionizing source results in different CNS and peripheral effects, depending on the development condition of the tissue-chemical systems affected. Similarly, exposure to ELF-RMF conditions on fetal days 13—16 and post-natal days 1—4 resulted in different behaviors. In an unpublished doctoral dissertation [17], Persinger tested rats on a delayed conditioned approach task. This testing situation, developed by M. F. Halasz [8] utilizes the step, impulse, and ramp signal procedures of schedule change. Applications of such changes in reinforcement schedules are associated with *transient* responses which can differentiate populations of animals that are not discriminable by more static schedule procedures [9]. Essentially, in this procedure rats were trained to press a bar for water reward in the presence of a tone and not to press the bar during the absence of

the tone. It was found that the rats exposed to the RMF on prenatal days 13—16 showed more responding during the no-tone period than control rats or RMF-neonatally exposed rats. A week later, half way through the session, a 10 second delay was instituted in a step-like manner so that water reward now was delayed for 10 seconds after the onset of the tone. The prenatally exposed RMF rats did not differ from their controls with respect to responses emitted during the delay period. However the rats that had been exposed to the ELF-RMF during their first three post-natal days, showed significantly greater response numbers during the delay period than controls or the prenatal animals. This effect was transient and attenuated on the consequent session. Such decrements in inhibition of responding during the no-tone (no reward) periods has been associated with changes in forebrain, including thalamic and hypothalamic tract contacts with the cortex, which were maximally developing during prenatal days 13—16. On the other hand, such behavior following the input of a step-delay has been shown to be more characteristic of changes in the cerebellum, certain parts of which (vermi) were maximally developing during neonatal days 1—4. In studies that are still in progress, the cortices of cerebellums in rats that were exposed neonatally to the RMF do not differ significantly in terms of cell layering or formation at the gross level from control animals. However, since the thyroid is implicated in the effect, the major changes should be with dendritic arborization of the Purkinje cells, which have not been stained to date. On the other hand, it would be predicted that the day 13—16 prenatal animals should show morphological changes in the forebrain, particularly in the hypothalamic-pituitary structures.

With respect to the effects of natural ELF and VLF frequencies upon the developing nervous system and endocrine-blood systems, little is known. No doubt the pregnant female in nature is not constantly exposed to high levels of ELF fields and it is not known to date exactly how long exposure must take place or at what time of fetal development before an effect is noticeable either in consequent behavior or physiology. The above studies indicate that exposure to ELF fields before birth can have different effects than after birth, when the neonatal electrical and endocrine systems are beginning to function by themselves and may be especially suceptible to outside stimuli. It seems plausible from both theoretical and empirical data that environmental factors could account for some of the "normal peculiarities" of CNS cytoarchitecture. Many experiments have shown that cells with the same genotype often show different

phenotypes. For example, Van der Loos [21] noted that 15—20% of the pyramidal cells in the macaque (and other species) were improperly oriented or inverted with respect to their cytological peers. Integrating these data with other studies, Jacobson [12] indicates that the orientation of dendrites is largely intrinsically determined for each class of neurons, but the direction of the axonal growth is more under the control of external factors. Perhaps one source of these changes is in the magnetic-electrical environment. The success of the studies to date show that the investigation of ELF and VLF offers many new opportunities for future work which most certainly will provide interesting insight into the relationship between cosmos and man.

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